FAILURE CHARACTERISTICS OF FULL DEPTH PRECAST SLABS WITH LOOP JOINTS

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ABSTRACT : This paper presents the testing results and analytical results of a single span slab formed by four panels of full depth precast units with band beams connected together with loop joints. The full depth precast units with thickness of 8.0 cm and a single span of 3.0 m were experimental studied. The single span slab was simply supported at each corner by steel columns of size 20x20 cm and tested under uniform load steps by means of sand bags. This slab was also analyzed by using the nonlinear finite element method with assuming nonlinear material properties. From the experiments, it was found that the slab had a linear behavior up to 40% of its ultimate load. After cracks occurred, the slab behaved nonlinearly and yielding of the main steel reinforcement was occurred at the load about 65% of its ultimate load with the span-to-center mid-span deflection ratio of about 250/1. Also, the slab had very high ductility at the failure and the mode of failure can be considered as a progressive failure. Comparing the analytical results with the experimental results implies that the full depth precast slab could be built as strong as the conventional slabs to sustain service loads for the ranges of 300-400 ksm provided that loop joints are used to connect the precast units. Increasing friction between the precast units and the joint concrete could increase load sustaining capacity of the slab. The slab performed in ductile manner with the ductility factor about 3.6.

KEYWORDS : *Nonlinear, Precast, Slabs, Full depth, Finite element*

1. INTRODUCTION

Conventional precast slabs are widely used in building construction. Most of these slabs are partially pre-cast which concrete topping is required for on-site installation. Moreover, these precast slabs are one-way slabs requiring beam supports at each slab end. Today, precast slabs are made in various section shapes such as solid planks, hollow cores, and double-T. Full depth precast slabs are mostly used as bridge decks to accelerate installation [1] and are used as concrete pavement to reduce construction time for repairing of concrete highway [2]. To form a large panel, the full depth precast slabs are connected together with loop joints which are, virtually, the most effective connections for this slab type. The effectiveness of the joint was studied under static and fatigue loading by using concrete beams [3] and it was found that the beam with the joint yields strength and stiffness similar to those of the ordinary beam without joints provided that the joint width was sufficient for development length of rebars. It should be noted that full depth precast slabs used in construction industry at present are one-way slabs which beam supports are required. Compared with the two-way slabs with the same design variables, the effectiveness of these slabs is lower due to the one-way distribution of the internal shear and moment in the slab. Therefore, to improve the effectiveness of the slabs, they should be segmentally and fully precast as two-way slabs with or without band beams. Also, to accelerate the construction, the slabs should be without topping. For installation, each slab is connected together with loop joints and supported directly by columns. The installed slabs are, hence, similar to flat slabs or slab with band beams. This paper presents the testing results and analytical results of a single span slab formed by four panels of full depth precast units with band beams connected together with loop joints. The slab was simply supported and tested under uniform loading by means of sand bags.

2. EXPERIMENTAL WORK

2.1 Details of full depth precast slabs

Dimensions and reinforcement of each precast unit are shown in figure 1 and dimensions of the single span slab are shown in figure 2. The slab was formed by four precast unit and simply supported by stiff steel columns at each corner.

2.2 Material properties

Concrete of all precast units was ready-mixed concrete supplied by CPAC. The concrete for poured strips was cast in-situ. Properties of the concrete and rebars are summarized in table 1.

2.3 Test set-up

The slab was simply supported at each corner by the stiff steel column of size 20x20 cm. Between the contacted surfaces of the slab and columns were placed with white cement mortar for the purpose of leveling. All surfaces of the slab were painted with the mixture of white cement and water to facilitate detection of concrete cracking. Displacement transducers were installed at slab center and at mid-point of each precast unit. Sand bags were used as uniform load and each sand bag weighed 1 kg. The overall set-up is shown in figure 3.

2.4 Testing

The slab was loaded step by step and each step was about 30 ksm which sand bags were uniformly distributed over the slab surface as shown in figure 4. A preload of approximately 90 ksm was applied to seat the testing slab before the beginning of the test. At each load step, the deflections were recorded after load sustaining for about 3 minutes and the slab was observed for concrete cracking. Then the next load step was begun. The slab was loaded to the point where the deflections increased dramatically with little or no increase in load.

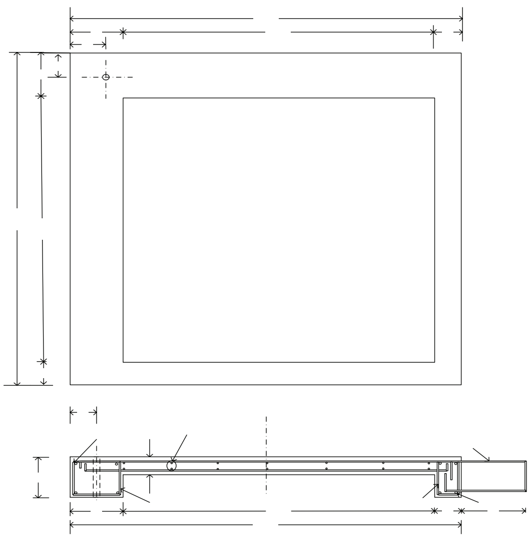

Figure 1 Dimensions and reinforcement of full depth precast slab (unit : cm)

3. TEST RESULTS

3.1 Load-deflection curves

Figure 5 shows an example of the load versus mid-span deflection curves of the slab used in this study. It was found that the slab had a linear behavior up to 250 ksm. After cracks occurred, the slab behaved nonlinearly and yielding of the main steel reinforcement was occurred at the load about 400 ksm with the center mid-span deflection of the slab of about 12 mm which the span-to-deflection ratio was about 250/1. After yielding,

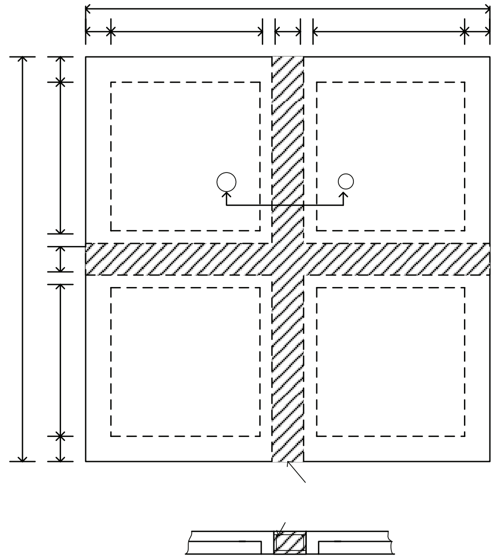

Figure 2 Dimensions of single span slab (unit : cm)

Table 1 Material properties

Cylinder f'$_c$ (ksc)		Rebars			
Precast unit	Poured strip	ϕ 6mm		ϕ 9mm	
		f_y(ksc)	f_u(ksc)	f_y(ksc)	f_u(ksc)
379	406	2751	3536	3033	4179

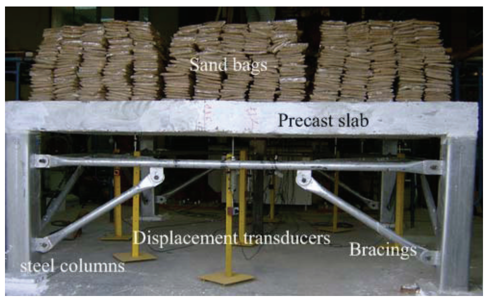

Figure 3 Test set-up

Figure 4 Uniform step loads

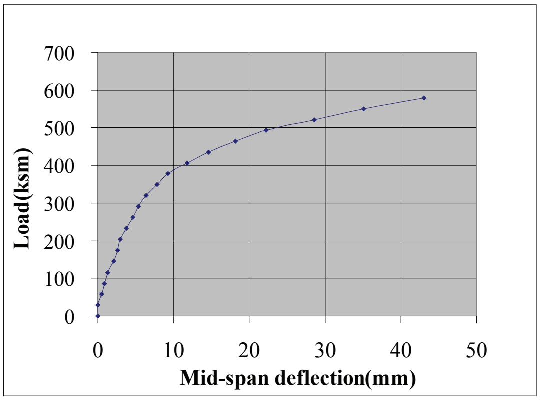

Figure 5 Load-mid span deflection curve of the slab

the slab stiffness reduced progressively with the increasing of the load step, causing a larger mid-span deflections for each load step. Maximum load was about 580 ksm with the maximum mid-span deflection of about 43 mm. Hence the ratio of the maximum displacement to that at yielding (ductility factor) is about 3.6.

3.2 Concrete cracking and deformation

In this study, the surfaces of the precast concrete in contact with the poured concrete were smooth surfaces. Figure 6 shows an example of the cracks occurred at the joint in the vicinities of the interfaces of the precast unit and the poured concrete at the mid-span of the slab at various load steps near the end of the test. These cracks occurred through out the slab width. At the center of the mid-span of the slab, complex cracks occurred as shown in figure 7. Virtually, there were no cracks found in other parts of the slab. The maximum deflection at mid span was about 43 mm which the span-to-deflection ratio was about 70/1, causing the slab end at each column to be tilted upward as shown in figure 8. This indicates that the slab has very high ductility at the failure and the mode of failure can be considered as a progressive failure.

4. ANALYTICAL RESULTS

4.1 Meshes of finite elements

The slab was analyzed by nonlinear finite element method using ANSYS program. Various elements of ANSYS [4] were used to model the slab system. Solid65 and Link8 elements were used to model concrete and main reinforcement, respectively. TARGE170 and COTA174 elements were used to model contact pairs along the interfaces of the poured concrete and the precast units and also to model the interfaces of the slab and the columns. Solid45 element was used to model the steel columns. In this analysis, the reinforcement of the slab and the integrated beams were modeled discretely by assuming that perfect bonding occurs between the concrete and the reinforcement. Elements of the concrete and the reinforcement are shown in figure 9 and figure 10, respectively.

Figure 6 Concrete cracking at the joint interfaces

Figure 7 Concrete cracking at mid-span

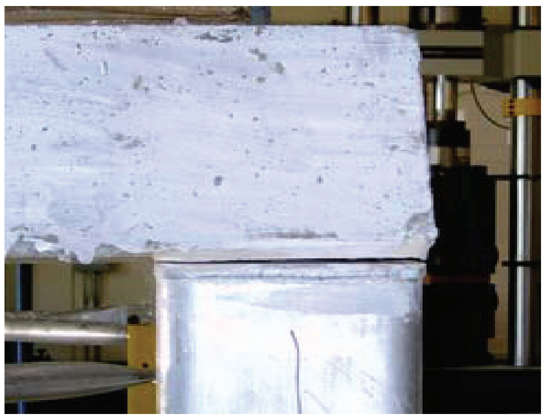

Figure 8 Slab corner tilted upward

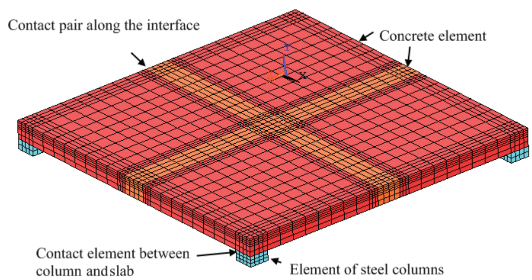

Figure 9 Meshes of concrete and steel columns

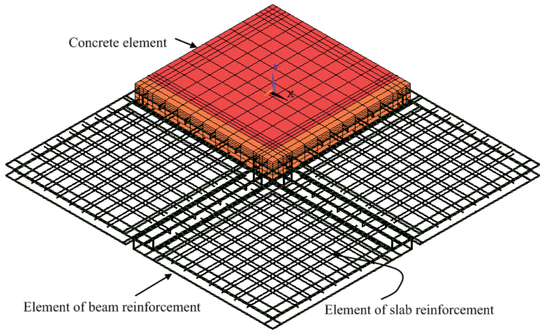

Figure 10 Meshes of concrete and steel bars

4.2 Material models

4.2.1 Material model of concrete

The expression of Maekawa and Okamura (1990) is selected as a nonlinear material model of concrete in compression as follows:

$$\sigma = K_o E_o(\varepsilon - \varepsilon_p)$$
$$K_o = e^{-0.73x(1-e^{-1.25x})} \quad (1)$$
$$E_o = \frac{0.141 f_c'}{\varepsilon_{peak}}$$
$$\varepsilon_p = \varepsilon_{peak}\left(x - \frac{20}{7}(1-e^{-1.35x})\right)$$
$$x = \frac{\varepsilon}{\varepsilon_{peak}}$$

when

K_o : fracture parameter represents the damage of concrete
E_o : initial stiffness of concrete, ksc
ε_p : plastic strain corresponds the total strain ε
ε_{peak} : peak strain of concrete under compression

The equation 1 associated with the average compressive strength of the slab yields the stress-strain curves as shown in figure 11.

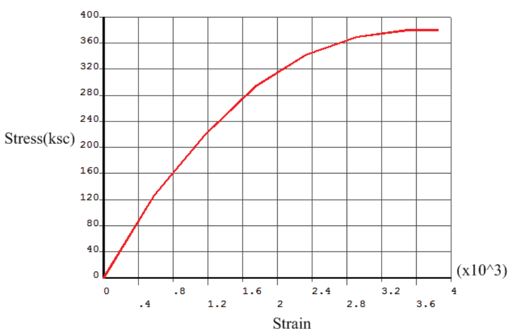

Figure 11 Typical stress-strain curve of slab concrete

4.2.2 Material model of steel

According to the testing of the rebars, the material was accurately simulated by Okamura's model (1991). The stress is linear elastic up to yielding point and after a certain yielding plateau, its behavior starts to be strain hardening in an exponential form as shown in figure 12 and the stress expressions are as follows:

$$\sigma = E_s.\varepsilon \qquad ; \ 0 < \varepsilon < \varepsilon_y$$
$$\sigma = f_y \qquad ; \ \varepsilon_y \le \varepsilon < \varepsilon_{sh} \quad (2)$$
$$\sigma = f_y + \{1 - e^{(\varepsilon_{sh}-\varepsilon)/k}\}(0.142 f_u - f_y) \qquad : \varepsilon > \varepsilon_{sh}$$
$$k = 0.047\left(\frac{281.8}{f_y}\right)^{2/3}$$

when

E_s : modulus of elasticity, ksc
f_y : tensile yield strength, ksc
f_u : ultimate tensile strength, ksc
ε : steel strain
ε_y : tensile yield strain
ε_{sh} : maximum tensile strain before strain hardening

The equation 2 associated with the average yield and ultimate tensile strength of the 9 mm rebar yields the stress-strain curve as shown in figure 12. The material of steel column was assumed to behave linearly.

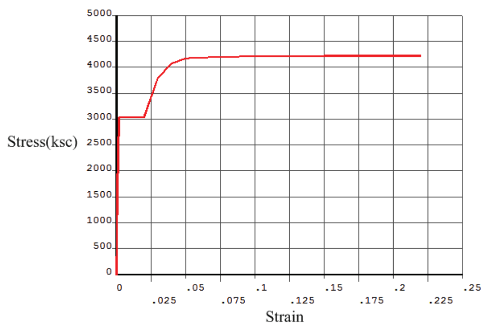

Figure 12 Typical stress-strain curve of ϕ 9 mm steel bar

4.2.3 Contact pair

For each contact pair, the material with higher strength was assumed to be the target surface while that with lower strength was assumed to be the contact surface. There are various contact types in ANSYS and, for this study, the interfaces between the precast units and the joint concrete could be slid and separated. Hence the normal type of contact was employed. The friction between the contact surfaces could play an important role in the slab performance under loading. Hence, from the literature reviews, it is recommended that the ranges of friction coefficient (μ) between 0.1-0.3 should be studied.

4.2.4 Analytical and experimental results

All of the material data and loading, including the finite meshes, were input to the program. Single load step with the smallest load step size of 0.001 and the maximum load step size of 0.1 were set for the nonlinearity. Convergence of the nonlinearity was controlled by using force L2 norm with the tolerance of 0.001. The analytical results and the experimental results are shown in figure 13. These results show that the experimental results and the analytical results were in good agreement in the initial loading up to about 250 ksm when the slab had the linear behavior. The analytical results associated with friction coefficient of 0.2 and 0.3 show strong performances, while those associated with friction coefficient of 0.1, 0.125 and 0.15 show in good agreement with experimental results after yielding. All the obtained yield loads from the analysis are higher than the experimental results. It is noted that cracking of concrete is not included in the analysis, causing the discrepancy between the analytical and the experimental results after concrete cracking before yielding. However, the analytical results associated with the friction coefficient of 0.1 are the best simulation of the slab performance in this study. Both of the analytical and experimental results show high ductility of greater than 3.

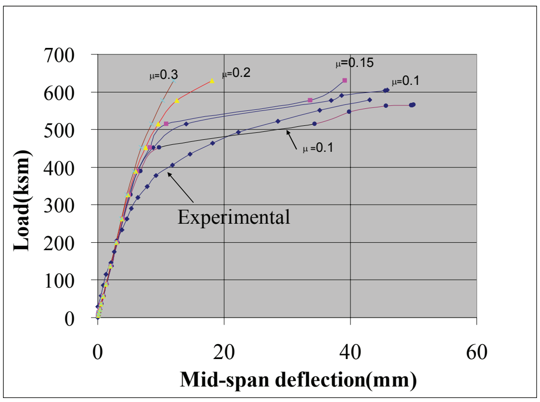

Figure 13 Analytical and experimental results

5. CONCLUSION

From the study, it can be concluded that

1) The slab had a linear behavior up to 40% of its ultimate load. After cracks occurred, the slab behaved nonlinearly and yielding of the main steel reinforcement was occurred at the load about 65% of its ultimate load with the span-to-center mid-span deflection ratio of about 250/1. Also, the slab has very high ductility at the failure and the mode of failure can be considered as a progressive failure.

2) The finite element models used in this study give the predicted results that in good agreement with those from the experiments.

3) Comparing the analytical results with the experimental results implies that the full depth precast slab could be built as strong as the conventional slabs to sustain service loads for the ranges of 300-400 ksm provided that loop joints are used to connect the precast units. Increasing friction between the precast units and the joint concrete could increase load sustaining capacity of the slab. The slab performed in ductile manner with ductility factor greater than 3.

6. AKNOWLEDGEMENT

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